ISSN: 2278-0181
NCMPC - 2019 Conference Proceedings

Investigation on Mechanical Behavior of LM4 Alloys Reinforced with Soda Glass

Mr. Koushik P K
Assistant Professor
Department of Mechanical Engineering, PESITM
Shivamogga, India

Mr. Mahanthesh M. R.
Assistant Professor
Department of Mechanical Engineering, PESITM
Shivamogga, India

Mrs. Ramya C R
Assistant Professor
Department of Mechanical Engineering, PESITM
Shivamogga, India

Mr. Siddanth P Jain
UG Scholar,
Department of Mechanical Engineering, PESITM
Shivamogga, India

***Abstract*— This work investigated the effect of mechanical behavior of LM4 alloys with addition of soda glass as a inter metallic particulate reinforcement material. The experiment was conducted by adding varying grain size and weight percentage fractions of soda glass powder micro particles of 212g, 304, sieve size and 2%, 5% respectively to molten LM4 alloy via stir casting route. On solidification, the samples were machined and mechanical properties test such as hardness and ultimate shear strength were carried out. The results indicated that the developed method was quite successful to obtain uniform distribution of inter metallic particles as a reinforcement material in the matrix of the composite. The hardness and ultimate shear strength were found to increase as the percentage of glass powder reinforcement particles increased except for ductility that decreased with increase in the percentage of reinforcement particles. Meanwhile the hardness of the composite goes on increasing with the decrease in grain size. As finer the grain size harder will be the composite. Therefore microns, of glass powder particles were found to be good reinforcement material for LM4 alloy.**

I. INTRODUCTION

Aluminium alloys have excellent mechanical properties coupled with good corrosion resistance. However, they possess poor wear and seizure resistance. To improve the above said properties, researchers have successfully dispersed various hard and soft reinforcements such as SiO_2, SiC, Al_2O_3, flyash, glass, WC, graphite, mica, and coconut shell char in aluminium alloys by different processing routes. Of all the processing routes, liquid metallurgy method is the most sought after owing to its several advantages such as economical mass production, near net shaped components can be produced. In recent years, aluminium alloy-based metal matrix composites (MMCs) are being explored as candidate materials in several interesting applications such as piston, connecting rod, contactors, where sliding is a key component.

Aluminium alloys (or aluminium alloys; see spelling differences) are alloys in which aluminium (Al) is the predominant metal. The typical alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures and components where light weight or corrosion resistance is required.

Alloys composed mostly of aluminium have been very important in aerospace manufacturing since the introduction of metal-skinned aircraft. Aluminium-magnesium alloys are both lighter than other aluminium alloys and much less flammable than alloys that contain a very high percentage of magnesium. Use of soda-lime glass as reinforcement in aluminium alloys has received little attention although it possesses high hardness and modulus with superior corrosion resistance. Of all the aluminium alloys, LM4 is quite a versatile matrix material to prepare metal matrix composites owing to its better formability characteristics and option of modification of the strength of composites by adopting optimal heat treatment.

Table: 1: Chemical composition of LM4 alloy by weight percentage

Element	Si	Cu	Mg	Fe	Mn
Wt.%	4.0-6.0	2.0-4.0	0.15 max	0.8 max	0.2-0.6

Table: 1 continued

Ti	Al	Ni	Zn	Pb	Sn
0.2 max	Balance	0.3 max	0.5 max	0.1 max	0.1 max

Silicon: After iron, is the highest impurity level in electrolytic commercial aluminium (0.01 to 0.15%). In wrought alloys, silicon is used with magnesium at levels up to 1.5% to produce Mg_2Si in the 6xxx series of heat-treatable alloys.

Copper: Aluminium-copper alloys containing 2 to 10% Cu, generally with other additions, from important families of alloys. Both cast and wrought aluminium-copper alloys respond to solution heat treatment and subsequent aging with an increase in strength and hardness and decrease in elongation. The strengthening is maximum between 4 to 6% Cu, depending upon the influence of another constituent present.

Manganese: Manganese is a common impurity in primary aluminium, in which its concentration normally ranges from 5 to 50ppm. It decreases resistivity. Manganese increases strength either in solid solution or as a finely precipitated intermetallic phase. It has no adverse effect on corrosion resistance. Manganese has a very limited solid solubility in aluminium in the presence of normal impurities but remains in solution when chill cast so that most of the manganese added is substantially retained in solution, even in large ingots.

Magnesium: Magnesium is the major alloying element in the 5xxx series of alloys. Its maximum solid solubility in aluminium is 17.4%, but the magnesium content in current wrought alloys does not exceed 5.5% the addition of magnesium markedly increases the strength of aluminium without unduly decreasing the ductility. Corrosion resistance and weldability are good.

Zinc: The aluminium-zinc alloys hence been known for many years, but hot cracking of the casting alloys and the susceptibility to stress-corrosion cracking of the wrought alloys curtailed their use. Aluminium-zinc alloys containing other elements offer the highest combination of tensile properties in wrought aluminium alloys.

Lead: Normally present only as a trace element in commercial-purity aluminium, lead is added at about 0.5% level with the same amount as bismuth in some alloys (2011 and 6262) to improve machinability.

1.2 Soda glass

Soda-lime glass, also called soda-lime-silica glass, is the most prevalent type of glass, used for windowpanes and glass containers (bottles and jars) for beverages, food, and some commodity items. Glass bakeware is often made of tempered soda-lime glass. Soda-lime glass accounts for about 90% of manufactured glass. Soda-lime glass is relatively inexpensive, chemically stable, reasonably hard, and extremely workable. Because it can be resoftened and remelted numerous times, it is ideal for glass recycling.

Soda-lime glass is prepared by melting the raw materials, such as sodium carbonate (soda), lime, dolomite, silicon dioxide (silica), aluminium oxide (alumina), and small quantities of fining [disambiguation needed] agents (e.g., sodium sulphate, sodium chloride) in a glass furnace at temperatures locally up to 1675 °C. The temperature is only limited by the quality of the furnace superstructure material and by the glass composition. Relatively inexpensive minerals such as trona, sand, and feldspar are usually used instead of pure chemicals.

Table: 2 Chemical composition of commercial soda lime glass

Element	SiO_2	Na_2O_2	CaO	MgO	Al_2O_3
Wt.%	71-73	14-15	8-10	1.5-3.5	0.5-1.5

II. LITERATURE REVIEW

M R Shivakumar, NVR Naidu., Metal Matrix Composites (MMCs) are an important class of composite materials which provide as alternate substitute for conventional materials, when desired properties are necessary for the applications. Aluminium alloy composites find applications where high strength to weight ratio is mandated. This work aims to characterize the thermal properties like thermal conductivity of LM6 aluminium alloy/glass powder composite developed by stir casting techniques. The effect of glass powder parameters is aimed at characterization on the developed composites. Taguchi's orthogonal array approach is adopted to reduce the experimentation burden. Parameter levels of glass powder are optimized for the desired thermal conductivity of the composite. [1]

Narayan W. Mannurkar, Prasad U. Raikar., The present investigation deals with influence of wear parameters like sliding speed, load and sliding distance on the dry sliding wear of aluminium LM4-T6 and LM6-M alloys. The alloys were prepared by conventional melting and casting routing technique and LM4 alloy followed the tempering process (T6). The Taguchi approach of design of experiment was employed to acquire data in a controlled manner. A pin-on-disc apparatus was used to investigate the wear behaviour of both alloys as per Taguchi's standard array. An Orthogonal array, the wear rate was optimized by using predicted Taguchi results. The multiple regression models were used to confirm the experimental results. The wear rate increased as percentage of silicon increases in an alloy. The microstructure analysis before wear revealed that as percentage of silicon increases as in the case of LM6M alloy, it leads to more degree of refinement of eutectic silicon as silicon content increases beyond eutectic composition. [2]

Puneeth H M, Girish K B, B H Vasudevamurthy., Aluminium matrix composites (AMC's) reinforced with Silicon Carbide (SiC) particles are being used for high performance applications such as Automotive, Aerospace, Military and Electrical Industries, because of their improved physical and Mechanical properties. In this context, A356.1 Aluminium alloy was reinforced with varying weight percentages of 0, 5.0, 10.0 and 15.0 Silicon Carbide, through Stir Casting Technique. The composites were characterized by Scanning Electron Microscope (SEM). Mechanical properties such as Hardness, Impact Strength, and Wear were carried out for different conditions. The results reveal that the Metal Matrix Composite (MMC'S) containing 15 weight percentage of Silicon Carbide reinforcement was shown more improvement in mechanical properties. [3]

S. Ilangovan., An investigation was carried out to understand the effects of cylindrical specimen on hardness, wear rate and the coefficient of friction of Aluminium alloy (LM4). The commercially available LM4 Aluminium alloy was melted in a crucible furnace under argon atmosphere. The molten metal was poured into sand moulds having dissimilar size holes. The cast rods were tested for Vickers micro-hardness, wear rate and the coefficient of friction. It was found that the hardness of the alloy varies with the diameter of the rod.

Wear rate is inversely proportional to the hardness of the alloy. It was observed that the yield strength and tensile strength are increases with hardness, whereas the % elongation decreases. [4]

Mr. Prashant Kumar Suragimath, Dr. G. K. Purohit., This work deals with fabricating or producing aluminium based metal matrix composite and then studying its microstructure and mechanical properties such as tensile strength, impact strength and wear behaviour of produced test specimen. In the present study a modest attempt has been made to develop aluminium based MMCs with reinforcing material, with an objective to develop a conventional low cast method of producing MMCs and to obtain homogeneous dispersion of reinforced material. To achieve this objective stir casting technique has been adopted. Aluminium Alloy (LM6) and SiC, Fly Ash has been chosen as matrix and reinforcing material respectively. Experiment has been conducted by varying weight fraction of Fly Ash (5% and 15%) while keeping SiC constant (5%). The result shown that the increase in addition of Fly Ash increases the Tensile Strength, Impact Strength, Wear Resistance of the specimen and decreases the percentage of Elongation. [5]

Outcome: From the above literature surveys, we can ensure that stir casting route will be an effective method in preparing aluminium composites and soda lime glass will be one of the most suitable reinforcement materials which can enhance alloy properties such as hardness, wear, shear etc.

III. OBJECTIVES

Problem Definition:

The aluminium alloys have wider range of applications in automotive where hardness plays a key role. In order to enhance its hardness without losing its other mechanical properties, we adopt cost effective and suitable reinforcement with soda lime glass which can overcome its hardness problems and can replace the high cost alloys.

Objectives of the work:

- To prepare the composites (specimens) by implementing stir casting technique effectively by varying the compositions
- To perform necessary machining on the composites to prepare it as test specimens of required specifications by turning and facing operations using the lathe.
- Effectively conducting the mechanical tests on the composites such as hardness and shear tests.
- Using the test results, studying the influence of soda lime glass on the hardness and shear strength of LM4 aluminium alloy after the reinforcement.

IV. METHODOLOGY

Materials

Among all other aluminium alloys, Al-$Si_5Cu_3Mn_{0.5}$ eutectic alloy (LM4) has lower melting temperature. This alloy is easy to cast and has reliable machining characteristics. Most of the automotive components are made by LM4 alloy. LM4 has not been exploited to very great extent. Compared to other reinforcing materials soda lime glass offers several advantages, in particular on the fronts of availability and cost. LM4 alloy was the matrix material and soda lime glass powder were added as the reinforcement. The soda lime glass powder was prepared by crushing the commercially available glass bottles. The glass powder was graded according to its fineness with standard sieves.

Calculations for Composites preparation

As per the availability, the dimensions of the moulds used are of length (l) =10cm and diameter (d) =1.2cm

Hence the mass of LM4 aluminium alloy is calculated for two specimens as follows:

wkt, density of LM4 aluminium alloy(ρ) = 2.7gm/cm^3

$$\text{Density} = \text{Mass}/\text{Volume}$$

$$\rho = m/v$$

Therefore, Mass (m) = Density (ρ) * Volume (v)

$$m = \rho*(\pi/4)*d^2*l*v$$

$$= 2.7*(\pi/4)*(1.2)^2*10$$

$$m = 30.53\text{gms}$$

Hence for 1 specimen, we require 30.53gms. So, for 2 specimens, it is 61.06gms. The allowance of 10% is added to this 61.06gms. So, the total mass required, m = 61.06 + 61.06 (10%) = 67.166gms.

Now by using Portable band saw machine, the alloy ingots are cut into pieces in order to obtain the required mass and then sensitive balancing machine. But here after cutting, an exact required mass value cannot be obtained but little higher mass is maintained which is further melted in the furnace.

Series are obtained by adding glass powders of 212µ and 300µ of sieve sizes in 2% and 5% weight percentages to the alloy. They are as follows:

Table: 3 Different compositions of LM4 and glass powder

Series	Mass of LM4 obtained (gms)	Mass of glass powder required(gms)
As cast	80	-
LM4 + 2% of 212µ glass powder	87	1.74
LM4 + 5% of 212µ glass powder	75	3.75
LM4 + 2% of 300µ glass powder	82	1.64
LM4 + 5% of 300µ glass powder	90	4.50

Preparation of the Composites

Induction furnace and Stir casting

An induction furnace is an electrical furnace in which heat is applied by induction heating of metal. Induction furnace capacities range from less than one kilogram to one hundred tonnes capacity and are used to melt iron, steel, copper, aluminium and precious metals. The advantage of the induction furnace is a clean, energy-efficient and well controllable process compared to most other means of metal melting. Most modern foundries use this type of and also more iron foundries are replacing cupolas with induction furnaces to melt cast iron, as the former emits lot of dust and other pollutants.

In the coreless type, metal is placed in a crucible surrounded by a water cooled alternating current solenoid coil.

Stir casting is an economical process for fabricating aluminium matrix composites. There are many parameters in this process which affect the final microstructure and mechanical properties of the composites. In this study, micron-sized inter metallic glass particles were used as a reinforcement, and LM4 + soda glass composites were fabricated at casting temperature 720°C and stirring time of 3 min. The mechanical properties of the composites were also evaluated.

Casting procedure

About 80gms of LM4 alloy was melted in a graphite crucible using induction furnace for about 1 hour. When the melt reached 720°C, which is well above the melting temperature of LM4 alloy, where hexachloro-ethene (C_2Cl_6) is the degassing agent; about 2gm of hexachloro-ethene tablet was added in order to avoid the hydrogen absorption from its surroundings by molten aluminium and dross was removed from the melt surface. Soda lime glass powder was added to molten aluminium and stirred manually for about 10mins by using mild steel stirrer which is coated by zircon (zircon oxide). After stirring the cover flux (45% NaCl+45% KCl+10% NaF) was added to form a layer on its top to avoid the chemical reaction between the aluminium and gases in the atmosphere

To gain the uniform distribution of glass particles in the molten aluminium alloy, the holding time was maintained for 5mins. Further the melt was poured to the pre-heated graphite mould. The composites were prepared by the above same procedure by varying the glass reinforcement parameters using the above methodology.

Flow chart diagram of casting process

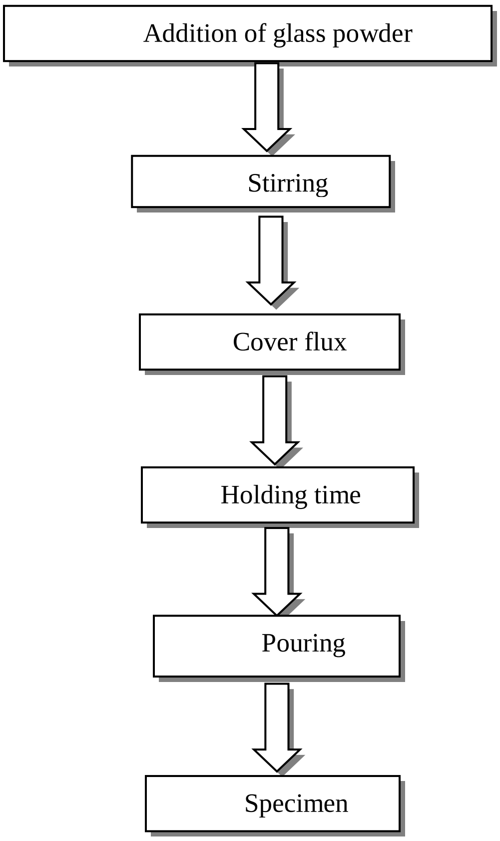

Fig.:1 Flow chart diagram of casting process

V. RESULTS AND CONCLUSION

Vicker's hardness test

In Vickers hardness test, the hardness of the material is determined by indentation of a square base diamond pyramid with an angle of 136° between opposite faces. This method is more versatile than other hardness testing machine. In this method, load may be varied from 1 to 100 kg. The load is selected in accordance with the size and hardness of the specimen.

The method is used for determining the hardness of the material of small cross section and materials of high hardness.

Procedure:

1. The load for the test is selected according to expected hardness of the specimen to be tested.
2. The specimen is placed on the testing table.
3. The timer is pressed to start the loading cycle.
4. The indentation is now projected on front focusing screen. The diagonal of impression in both axes is measured.
5. The above procedure is repeated by changing position of indentation on specimen and corresponding readings are noted down.

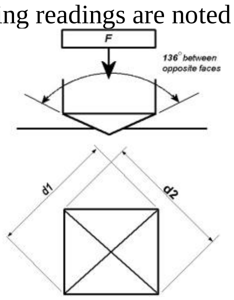

Fig.2: Indentation

Table:4 Readings of Vicker's hardness test

Material used	Load " F" (Kg)	Diagonal length of indentation			Vicker's Hardness Number
		d 1 (mm)	d_2 (mm)	Mean 'd'	VHN=[2Fsin (136/2)]/d^2 VHN = 1.854F/d^2
As cast	20	0.752	0.741	0.746	66.628
LM4 + 2% of 212µ glass powder	20	0.621	0.667	0.644	89.406
LM4 + 5% of 212µ glass powder	20	0.620	0.621	0.620	96.462
LM4 + 2% of 300µ glass powder	20	0.622	0.694	0.658	85.64
LM4 + 5% of 300µ glass powder	20	0.643	0.632	0.637	91.38

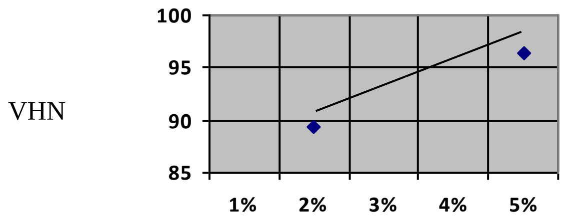

Fig.3: VHN v/s % of 212µ glass powder

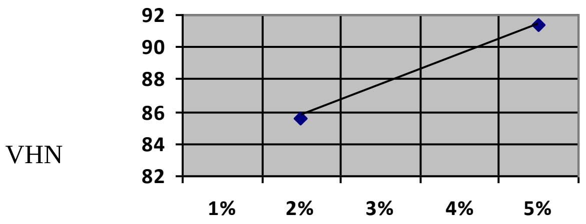

Fig.4: VHN v/s % of 300µ glass powder

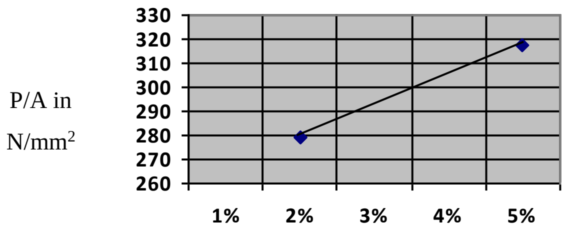

Fig.5: Ultimate shear strength v/s % of 212µ glass powder

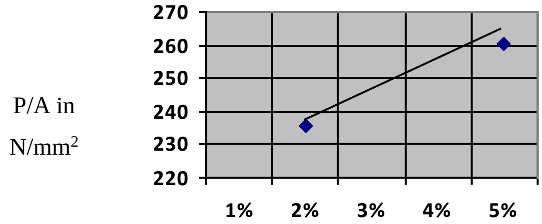

Fig.6: Ultimate shear strength v/s % of 300µ glass powder

Shear strength test

This test is carried out in Universal Testing Machine (UTM) using shear testing apparatus called shackles which will be placed on its surface. It is carried out for single shear where the specimen gets fractured or sheared off at some point of load. The ultimate shear strength will be known by considering that shear load and the area of cross section of the specimen.

Procedure:

1. The diameter of the specimen is measured by using micrometer.
2. Specimen is fixed in the shackles for single shear.
3. Apply load slowly right angle to the axis of the specimen through the central block.
4. Load at fracture is noted down.
5. The ultimate shear strength for single shear is calculated.

Table: 5 Readings of Shear strength

Material	Type of shear	Día of the specimen(d) in mm	Fracture load (P) in N	Area of the specimen (A) in mm^2	Ultimate shear strength in N/mm^2
As cast	Single	8	10.25	50265	203.919
LM4 + 2% of 212µ glass powder	Single	8	14.05	50.265	279.518
LM4 + 5% of 212µ glass powder	Single	8	15.95	50.265	317.318
LM4 + 2% of 300µ glass powder	Single	8	11.28	50.265	235.75
LM4 + 5% of 300µ glass powder	Single	8	13.08	50.265	260.22

Applications:

- It is suitable for most general engineering purposes like cylinder-heads, crank-cases, junction boxes, gear boxes, clutch cases, switch gear covers, instrument cases, tool handles and house hold fittings, office equipment, electrical tools etc.,
- It's casting characteristics permit it to be used for the production of thick and moderately thin forms and also for castings required to be pressure tight.
- It is mainly used in cast form in important components like pistons, engine blocks, cylinder liners, rocker arms, air conditioner compressors, brake drums riser angle brackets etc.

VI. CONCLUSION

By this, the stir casting method for the preparation of composites is effectively implemented. The glass particles are uniformly reinforced throughout the aluminium alloy i.e., LM4.From hardness test, it is seen that smaller the size of glass particles reinforced greater will be the hardness of the material and also as the weight percentage of glass particles increases, hardness also increases. Graph 1 and Graph 2 justify these. Similarly, from shear test, it is seen that smaller the size of glass particles reinforced greater will be the shear strength of the material and also as the weight percentage of glass particles increases, shear strength also increases. Graph 3 and Graph 4 justify these.

The glass powder parameters namely weight % and particle size of glass of the composite reduces the thermal conductivity of the composites. Wear rate will be inversely proportional to the hardness of the alloy as per Archard's adhesion theory of wear. Due to its light weight, high strength to weight ratio, high wear resistance, low coefficient of thermal expansion, low thermal conductivity, high corrosion resistance, good cast performance, good weldability etc. which makes them attractive material in aerospace and other engineering sectors, where they can successfully replace ferrous components in heavier applications

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